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A model of pecan tree growth for the management of pruning and irrigation

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ABSTRACT

Pecans [*Carya illinoensis* (Wangenh.) C. Koch] are an important cash crop in arid southwestern USA. The pecan is an alternate bearing tree and its water use is greater than that of most row crops. Irrigation, pruning amount, and timing must be effectively managed to reduce alternate bearing for maximum profits. A simulation model of pecan growth and yield is a potential tool for managing irrigation and pruning amounts and timing. An object-based pecan growth model was developed and validated to simulate daily pecan tree dry matter production, biomass allocation to leaves, nuts, trunk, and branches, and alternate bearing according to inputs of weather data, soil condition, irrigation, and pruning operations. Daily dry matter production per unit of evapotranspiration (water use efficiency) was calculated as a function of average vapor pressure deficit. Biomass allocation functions were derived from tree growth measurements at an orchard near Las Cruces, NM. Alternate bearing was simulated as a function of the level of root starch reserves. It was theorized that the setting of pistillate flowers and subsequent nut yields are proportional to the level of root starch reserves in the preceding dormant phase (winter). Mathematical functions for the effects of irrigation and pruning on tree growth and yield were derived from the literature and available data. The model was calibrated using 2002, historical, and literature data and validated against 2003 and 2004 data obtained from a mature pecan (Western Schley cultivar) orchard near Las Cruces, NM. Overall accuracy was above 89% for simulated total dry matter production, nut yield, tree height, and diameter at breast height (DBH). This model was found to adequately simulate the effects of climate, irrigation, and pruning on pecan tree growth, nut yield, and alternate bearing. It can potentially be used to schedule and estimate the amount of irrigation and pruning to optimize pecan nut yield.

1. Introduction

Pecan trees are an important crop in the irrigated agriculture of southwestern US. The main cultivar is 'Western Schley'. The water use of pecan trees is greater than that of most row crops and is estimated to be 100–130 cm per season for mature pecan trees grown in the El Paso, TX–Las Cruces, NM area (Miyamoto, 1983). More recent measurements in 2003 from 21-year-old pecan trees located 7 km south of Las Cruces, NM gave a maximum daily ET of 10.6 mm day^{-1} and a seasonal

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(May 1–November 31) total of 116 cm (Wang et al., 2006). Flood irrigation is the oldest and most common irrigation system used in New Mexico orchards. Typically, annual irrigation is about 2 m for pecan orchards (Wang et al., 2006). Irrigation amount and timing should be based on the ET of the pecan trees to optimize growth and production (Stein et al., 1989; Miyamoto, 1985).

Pecan trees are usually spaced about 9 m × 9 m for high density planting (Herrera, 2005). Tree crowding and excessive shading reduce productivity (Andersen and Crocker, 2004). Crowded trees also make agricultural operations such as spraying and harvesting more difficult. Pruning can solve these problems. The diameter of branches that are pruned can range from 0.01 to 0.11 m and total dry weight removed can be from 10 to 130 kg $tree^{-1}$. Pruning includes mechanical hedging and selective pruning. In the southwestern US, hedging is the common pruning practice. In other areas where pecans are grown hedging is not common or less common than selective pruning. Our model work will focus on mechanical hedging pruning practice for the southwestern US. Pruning may reduce the yield and alter the bearing phase (Worley, 1985, 1991).

'Western Schley' is a fairly strong alternate bearer compared to other pecan cultivars (Conner and Worley, 2000). The tendency for alternate bearing increases with age and increasing yield. For example, at Stahmann Farm in Las Cruces, NM, the average yield from a mature orchard is 2500 kg ha^{-1} with yields of 1400 kg ha^{-1} in an off year and 3600 kg ha^{-1} in an excellent year (personal communication). Pecan nut prices are usually low in years of high yield (McEachern et al., 1997). Managing a pecan orchard to adjust alternate bearing to an optimal level (e.g., being out of sync with other orchards) will result in maximum profits.

Modeling pecan yield is complicated by the occurrence of alternate bearing. Several investigators have found that flowering and nut yield are related to the amount of carbohydrate reserves stored from the previous season (Malstrom, 1974; Smith and Waugh, 1938; Wood, 1989, 1991; Wood and McMeans, 1981; Worley, 1979a,b). There was a strong relationship between nut yield and January root starch concentrations and nut yield was not significantly related to shoot carbohydrate reserves (Smith and Waugh, 1938; Smith et al., 1986; Wood, 1989). Irregular bearing in pecan has been attributed to failure of pecan trees to annually initiate and set sufficient numbers of pistillate flowers (Amling and Amling, 1983). Pistillate flower differentiation occurs in the spring, when the outer bud scales are shed and buds are swollen, but before the inner bud scale is broken (Wetzstein and Sparks, 1983).

To simulate pecan tree growth the total dry matter production needs to be calculated. Dry matter production can be estimated from the product of water use efficiency (WUE, kg ha^{-1} cm^{-1}) and ET (cm). Plant WUE variation is strongly affected by vapor pressure deficit (VPD) (Law et al., 2002; Gutschick, in press). Law et al. (2002) analyzed monthly WUE and VPD data for evergreen conifers, deciduous broadleaf forests, crops and grasslands from different AmeriFlux sites, and found that as VPD increased, WUE decreased.

The total dry matter production should appropriately be allocated to different tree components. Lacointe (2000) gave a comprehensive review regarding assimilation–allocation models. The source/sink models have been widely used. The sources are the leaves that assimilate carbon. The sinks are the components (trunk, branches, leaves, nuts, and roots) that consume or store assimilates. Two main subclasses of models can be distinguished in the source/sink model. One is the proportional model that allocates assimilate flux proportional to the sink demand, not exceeding it. The other is the hierarchical model, in which sink strength is defined as a maximum growth rate or demand, and the different sinks are ranked according to a priority-level order or hierarchy. For example, Grossman and DeJong (1994) proposed an approach for peaches with the assumption that sink strength was greatest for organs closest to the source.

The allocation parameters can be measured experimentally. Point and band dendrometers have been used to measure the change in the diameter and growth of trunks and branches for forest trees since the 1950s (Clark et al., 2000). If a very sensitive linear variable differential transducer (LVDT) is used in the dendrometer, a data logger can continuously record the diameter changes throughout the day (Goldhamer et al., 2003). The biomass of new growth can be calculated according to the change in diameter, the length of the trunk or branch, and wood density.

A pecan crop model is needed to understand the complex relationships among weather, irrigation, and pruning timing and amount as it affects growth and nut yield. This model needs to simulate the alternate bearing effects on the pecan yield and be able to allocate the total biomass to major components of the tree.

Passioura (1996) makes the argument that models fall into two categories: (1) mechanistic models developed for scientific understanding of the processes in nature or (2) functional models developed to solve management problems. The mechanistic models are based on hypotheses, which may or may not be correct, of how plants grow. Often these models are difficult to run because of the large number of inputs and state variable changes that occur in the models that cannot be measured in the field. On the other hand, functional models are robust and easy to understand and run but are not necessarily applicable outside the environmental conditions that were used in their development. The functional models can illuminate, to a limited degree, the mechanistic aspect of plant growth within the environment under which they were developed.

A simulation model to be developed as a user-friendly decision support system for irrigated crops should include all objects necessary to simulate crop growth using either mechanistic or empirical functional relationships (Acock and Reynolds, 1989; Reynolds and Acock, 1997). Object-oriented decision support programs model real world objects with software counterparts and each object consists of encapsulated data (attributes) and methods (behavior and interactions). Objects interact with each other and with their environment. Objects also provide interfaces by which users can change attributes or execute methods.

The purpose of this research was to develop and test a user-friendly and object-oriented pecan growth model for the management of irrigation and pruning. Excel (Microsoft Corporation) spreadsheets are the user-interfaces that allow the user to easily change the parameters and mathematical